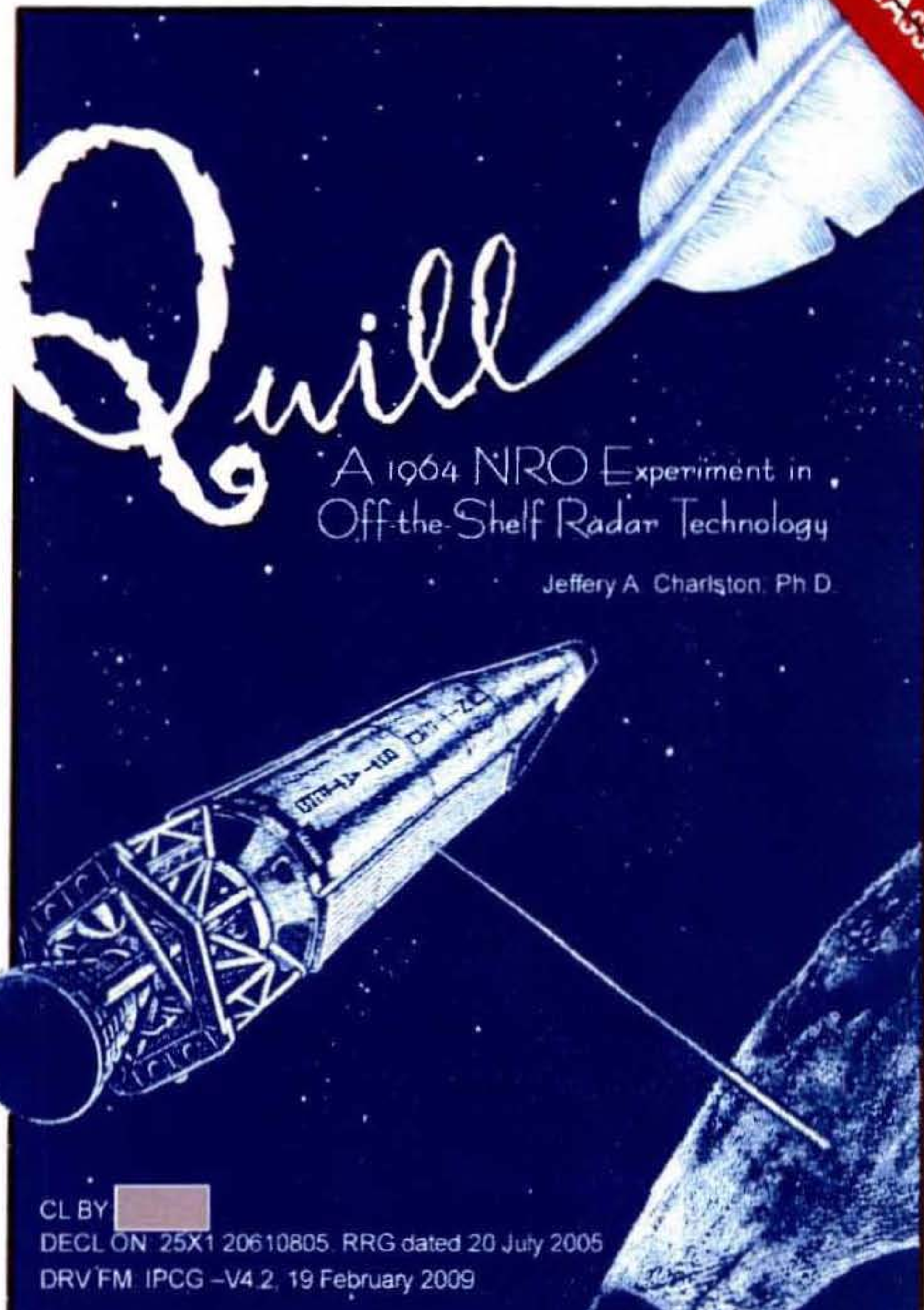
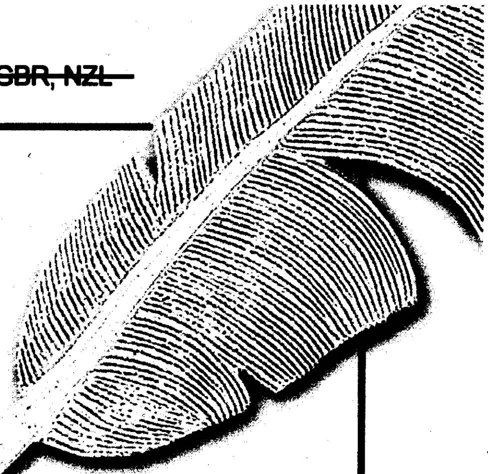
CLASSIFIED

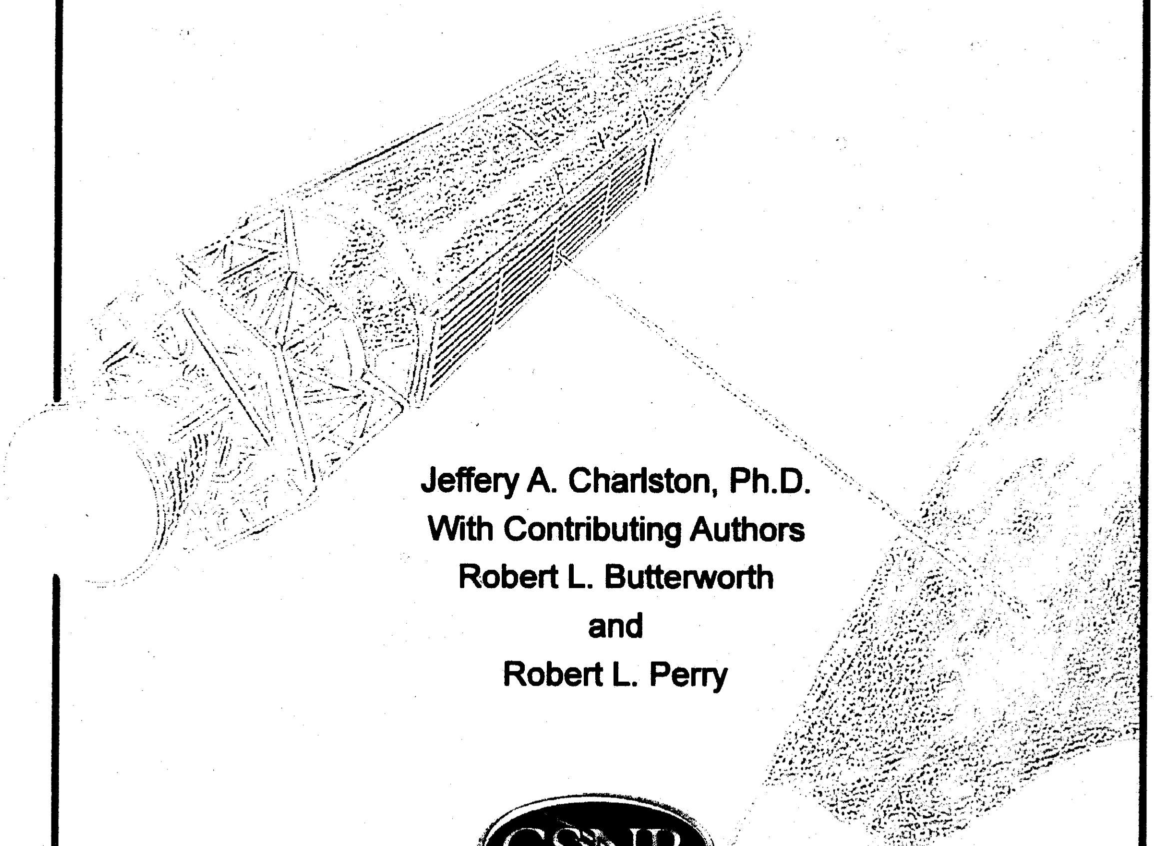


NATIONAL RECONNAISSANCE OFFICE 50 YEARS OF VIGILANCE FROM ABOVE



Quill

A 1964 NRO Experiment in Off-the-Shelf Radar Technology



Jeffery A. Charlston, Ph.D.
With Contributing Authors
Robert L. Butterworth
and
Robert L. Perry

CENTER FOR THE STUDY OF
NATIONAL RECONNAISSANCE

AUGUST 2011

(U) CONTENTS

(U) **NOTE:** Portions marked as REL are REL TO USA, FVEY unless otherwise marked.

(U) FOREWORD

~~(S//TK//REL)~~ The development of synthetic aperture radar (SAR) imaging for intelligence purposes began before the establishment of the National Reconnaissance Office (NRO). Under the NRO's coordination, scientists and engineers steadily overcame the technological and bureaucratic barriers to achieve radar imaging's potential. On 21 December 1964, Quill, the world's first satellite-borne SAR launched from Vandenberg Air Force Base, California.

~~(S//TK//REL)~~ Quill was a successful experimental program. It is remarkable that it was built using technology already available, saving both time and money. Dr. Jeffery Charlston captures these themes in this concentrated account of the Quill program. For the reader, the Quill program offers knowledge on experimental programs, working with bureaucracy, using existing technology, and finding the right customer.

~~(S//TK//REL)~~ Dr. Charlston builds upon the work of others in presenting this brief history of Quill. As the reader gains insight into the beginning of SAR, I challenge the reader to take the lessons of the past and look into the future at how this experiment can be applied to national reconnaissance efforts.

Robert A. McDonald, Ph.D.
Director, Center for the Study
of National Reconnaissance

(U) PREFACE

~~(S//TK//REL)~~ In addition to being the first orbital radar-imaging satellite and a remarkably cost-effective experiment conducted with available hardware, Quill played a significant role in pioneering holography, optical computing, and applied Fourier transforms. The program is an important missing part of unclassified aerospace history and the National Reconnaissance Office's (NRO's) acknowledged contributions to science and industry.

(U) Quill's remarkable achievements have been previously discussed in two classified histories. Robert L. Perry completed *Quill: Radar in Orbit* in 1973 as part of his multivolume work for the National Reconnaissance Office's Program A, *A History of Satellite Reconnaissance*. Robert L. Butterworth prepared another history of the program, *Quill: the First Imaging Radar Satellite* as part of a larger effort for the previous NRO History Office in 2002, revising it for the successor, Center for the Study of National Reconnaissance (CSNR) in 2004. The author further revised and edited Butterworth's work while serving as a senior historian for CSNR from 2006 to 2008. That effort is the origin of this article, and large portions of it are duplicated here.

(U) On 27 November 2009 the Director of National Intelligence concurred with the Director of the NRO's decision to declassify the fact of Quill as a 1964 NRO experiment in radar imagery. All additional information about the Quill program remains classified pending additional guidance.

Jeffery A. Charlston, Ph.D.
Co-chair, Quill Declassification
Integrated Process Team (IPT)

(U) INTRODUCTION

~~(S//TK//REL)~~ In the early 1960's the United States successfully began collecting satellite imagery from space. The collected imagery verified many Soviet strategic nuclear capabilities. U.S. imagery satellites faced one significant limitation, however, collection through cloud cover and the darkness of night. The story that unfolds in the following pages illustrates the United State's first attempt to address this limitation from space, the Quill experiment.

~~(S//TK//REL)~~ Quill was a small experimental satellite program used to test whether radar returns from space could peer through clouds and darkness. The experiment proved radar imagery derived from space-based sensors was possible, setting a foundation for building a critical reconnaissance capability for the nation.

~~(S//TK//REL)~~ By the time Quill was under development, the Soviet Union had already demonstrated full strategic nuclear capabilities and had also proven adept of obscuring and masking their activities in the large expanse of the Soviet homeland. The United States recognized that additional reconnaissance capabilities were required to counter the Soviet threat. In order to help counter the Soviet threat, the National Reconnaissance Office (NRO) was established on 6 September 1961 by an agreement between the Central Intelligence Agency (CIA) and the Department of the Defense (DoD). The purpose of the NRO was to enhance coordination, collaboration, and management of satellite reconnaissance programs under development by the CIA and DoD elements. Within the NRO, the Department of the Air Force supported a Los Angeles based element that undertook the Quill experiment.

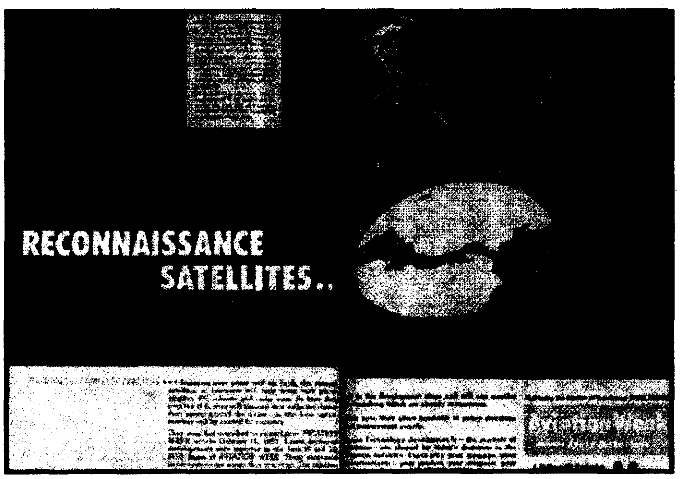
~~(S//TK//REL)~~ U.S. industrial partners and research laboratories had already supported efforts to collect imagery derived from radar sensors on airborne platforms. Some the country's best minds were working issues associated with space-based collection including radar sensors. Quill was the beneficiary of an environment where government, research, and industrial engineers and scientists identified a space sensor opportunity and successfully carried out a proof of concept experiment. [redacted] yet the Quill experiment was an important early victory in proving the potential for more sophisticated radar imagery systems.

~~(S//TK//REL)~~ Dr. Jefferey Charlston has presented this fascinating story in a commendable and brief form. This history will benefit all practitioners of national reconnaissance who continue to support the defense of the nation through reconnaissance from space and are interested in the first steps leading to fully successful space reconnaissance programs.

James D. Outzen, Ph.D.
Chief, Historical Documentation and Research
Center for the Study of National Reconnaissance

(U) OVERVIEW

(U) The U.S. Air Force began planning for space-based reconnaissance before the Soviet Union launched its first satellite on 4 October 1957. News of those Air Force plans, however, drew popular attention only after Sputnik's strategic implications startled the American public. *Aviation Week* magazine publicized the existence of an Air Force contract with Lockheed Missiles and Space Company (see figure 1) for the development of Weapons System 117L (WS-117L) just ten days after the launch of the Soviet radio beacon satellite. The reconnaissance satellite, also referred to as Pied Piper, "would carry television, photographic cameras, [and] infra-red spotter or radar scanner systems."[1]



(U) Figure 1—1958 Radar Satellite (image: UNCLASSIFIED) source—(U) *Aviation Week and Space Technology,* 69:10 (8 September 1958)

(U) The generically designated WS-117L became the ancestor of all American reconnaissance satellites, including systems designed to produce radar imagery. Analysts working for the newly renamed *Aviation Week and Space Technology* accurately included radar imagery systems in their September 1958 predictions for emerging satellite capabilities.[2] That prediction came true six years later with the launch of a satellite called Quill.

(U) ORIGINS

(U) The public received an indication of the intelligence potential of satellite-borne synthetic aperture radar (SAR) as early as 20 April 1960. On that date the U.S. Army released images of American cities taken by an aircraft-mounted AN/UPD-1 side-looking airborne radar (SLAR) system. That technology, traced back to World War II radar navigation systems, proved capable of generating recognizable images at night and through cloud cover. *Washington Post* reporter

---

[1] (U) "USAF Pushes Pied Piper Space Vehicle," *Aviation Week* (14 October 1957), 26. U.

[2] (U) *Aviation Week and Space Technology* 69:10 (8 September 1958), 100-101. U.

John Norris correctly concluded that the necessary hardware could be mounted on a reconnaissance satellite (see figure 2).[3]

(U) Figure 2—1960 Airborne Radar Image (image: UNCLASSIFIED) source—(U) *Washington Post* page 1, 20 April 1960.

(U) Adapting the SLAR capability for use on a satellite offered numerous advantages. Airborne SLAR used the real aperture of the radar unit's antenna, and had to measure and compensate for the incidental motion of the parent aircraft. Space vehicles promised nearly perfect stability and predictable motion. This allowed the radar unit to record signal returns over a considerable distance to form a virtual antenna—a SAR. The physically smaller antennas required for a satellite actually improved resolution with SAR by "painting" the resulting image with a smaller brush, and distance from the target proved effectively irrelevant.[4]

(U) Development of America's first reconnaissance satellites was already well under way beneath a steadily growing cloak of secrecy. The core WS-117L design concepts, E-1 and E-2, sought to provide a near-real time imagery capability. In principle a near-real time system would transmit images back to Earth almost as quickly as they could be collected, allowing for rapid processing and evaluation. Decision makers and military planners could use this capability to follow critical events as they developed.

[3] (U) John G. Norris, "New Radar-Photo 'Spy' Scans Afar," *Washington Post*, 20 April 1960, 1. U.

[4] ~~(S//TK//REL)~~ [redacted] project engineer for the Quill radar, interview with Robert Butterworth, Litchfield Park, Arizona, 10 May 2001. NRO history files. TS//TK.

(U) No matter how desirable that capability might have been, the era's television camera, data storage, and bandwidth capabilities presented formidable barriers to obtaining near-real time imagery from orbit. Using photographic film for data storage in what came to be known as a film-readout system promised only a partial solution. Classified WS-117L design alternatives included a simpler film return option as a backup approach.

(U) The Central Intelligence Agency's Corona program sought to employ that second-choice method until WS-117L produced a near-real time system. In place of the complex mechanisms required to process, scan, and transmit film images in the absence of suitable digital technology, the alternative approach simply stored the exposed film in a small reentry vehicle for return to Earth. The Corona program successfully returned the first intelligence imagery from space on 18 August 1960 and remained operational as the concept of space-based radar imagery developed.

~~(S//TK//REL)~~ During the summer of 1961 Colonel William G. King served as deputy director of the Air Force's Special Projects staff in Los Angeles. That organization was designated as Program A of the National Reconnaissance Office (NRO) with the secret establishment of the new intelligence organization on 6 September 1961. King's office worked closely with Lockheed on satellites and launch vehicles under both its acknowledged and classified identities, and King soon headed a study group looking for new ways to use satellites for national reconnaissance.

~~(S//TK//REL)~~ In the late fall of 1961 this study group took up the possibility of launching a proof-of-concept SAR satellite.[5] An operational SAR satellite would greatly improve the Air Force's capability to conduct post-strike analysis in the event of a nuclear war, a possibility weighing heavily on strategists' minds at that time.[6] After several months of continued effort, this project had matured enough for King to officially propose the experiment to NRO Director Joseph V. Charyk, who approved it in mid-November 1962.[7]

~~(S//TK//REL)~~ King had already assigned Major David D. Bradburn, an electrical engineer with long experience in the Air Force's Air

[5] (U) Ibid.

[6] (U) Robert L. Perry, *Quill: Radar in Orbit* (NRO, 1973), 1-2. TS//BYE.

[7] (U) NRO headquarters (DNRO Charyk) to Maj. Gen. Greer, head of the Air Force Special Projects (SAFSP) activities on the West Coast, 21 November 1962. ARC Job 199880073, box 1, folder 100. S. Captain Gorman, USN, "SAFSP Historical Chronology CY 62," ARC Job 199800072, box 3, folder 11. S. Charyk to McCone, 14 December 1962, "Memorandum for Mr. McCone," ARC Job 199700046, Box 4, Folder 14. TS//BYE.

Research and Development Command, to direct the effort. Bradburn summoned a group of industrial and scientific experts, including representatives of Lockheed and Goodyear Aerospace Corporation, to a meeting in Los Angeles without telling them the subject. It turned out to be the official start of the SAR satellite demonstration, now known by the classified name "P-40." The satellite itself received the code name "Quill."

~~(S//TK//REL)~~ Although overshadowed by the Corona program and other efforts of the young NRO, Quill remains an example of sound project management and the successful use of available technologies for a new purpose. Robert Perry summarizes its accomplishments:

> ~~(S//TK//REL)~~ In the first 20 years of reconnaissance satellite program activity in the United States, Quill was the only program that substantially conformed to initial cost, schedule, and performance estimates, and the only satellite program of any nature to proceed from start to finish with a perfect record in launch, orbital operations, readout, and recovery.[8]

(U) DEVELOPMENT

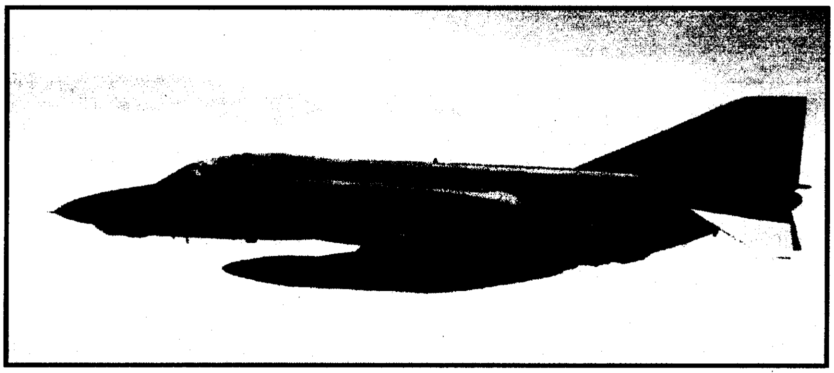
~~(S//TK//REL)~~ The group quickly requested proposals from industry, and contracts formalizing Lockheed and Goodyear's preexisting cooperation in the project were awarded in November 1962. The Lockheed team in Sunnyvale, California already providing the Agena vehicle for the Corona satellite assumed responsibility for overall systems engineering and technical direction, together with providing the upper stage/satellite body and associated subsystems for Quill. Goodyear would manufacture the radar payload and cooperate in the design, testing, and operation of the experimental satellite program. The contract called for two identical vehicles, designated as missions 2355 and 2356, with first launch in April 1964. A third vehicle's payload would also be prepared, but no booster was identified for it.[9]

~~(S//TK//REL)~~ Defense Secretary Robert S. McNamara's senior technical advisor, Dr. Eugene Fubini, raised an immediate objection to the cost of the program. He noted that the budget for acquisition

[8] (U) Perry, 1. Of course the fact that Quill proved to be a single-flight program must be taken into account in weighing Perry's assessment.

[9] ~~(S//TK//REL)~~ Information about the contractual arrangements for Quill is drawn from the Bradburn interview with Robert Butterworth, NRO history files, S//TK, and from Lockheed Aircraft Corporation, *Vehicle 2355 System Report: Volume 1: Summary* (Sunnyvale, California: Lockheed Missile and Space Co., 31 March 1965), pp. 8ff., S//BYE.

of the project's five radar units amounted to five times the cost for the existing APS-73 radar upon which it was based.[10] The radar was designated KP-II (Knowles Project Number Two, after Goodyear Aircraft Company president T. A. Knowles) in its secretly modified form, and actually represented a form of the AN/UPQ-102 pulsed-Doppler system that Goodyear was then developing for the Air Force RF-4C reconnaissance aircraft (see figure 3) from the earlier APS-73.[11] To meet P-40's requirements, Goodyear would remove unnecessary aerial subsystems and prepare this cutting-edge technology for operation in space. The preliminary budget covered all of the associated costs, including launch services. Bradburn's explanation satisfied Fubini and the Pentagon released funds to initiate the experiment.[12]



(U) Figure 3—RF-4C Aircraft (image: ~~S//TK//REL~~)

~~(S//TK//REL)~~ Bradburn focused the P-40 experiment on demonstrating orbital functionality. Lockheed emphasized this proof of concept mission, establishing a goal of 50-foot resolution in both azimuth (across track) and slant range (along track).[13] Secondary mission objectives assessed the radar system's performance, determined the limits imposed by the Agena platform, gathered technical information on radar operation and ground recording equipment, and sought information to improve subsequent radar system designs.

~~(S//TK//REL)~~ The project did not seek to develop new technology or become the basis for an operational reconnaissance system.[14] In Bradburn's view, the orbital experiment sought to answer only two

[10] (U) Perry, 21-22.

[11] (U) The first production RF-4C aircraft were delivered to the Air Force in September 1964.

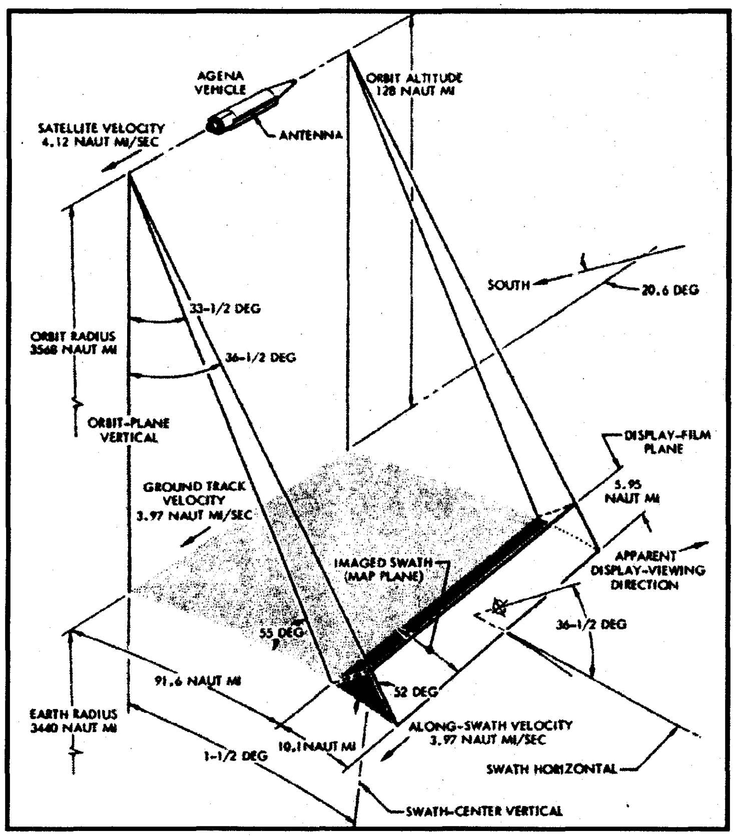
[12] (U) Perry, 21-23.

[13] ~~(S//TK//REL)~~ Lockheed, *Vehicle 2355 System Report 1,* 15.

[14] (U) Joseph V. Charyk, Director, National Reconnaissance Office, to Mr. McCone, memorandum, 14 December 1962, p. 4. ARC Job 199700046, box 4, folder 14, TS//BYE. "Status of Satellite Reconnaissance Programs," 13 November 1963, p. 7. ARC Job 199700046, box 4, folder 14, TS//BYE. [redacted], "Satellite Reconnaissance," July 1963, p. 20. ARC Job 199700046, box 46, folder 14, TS//BYE.

questions: could the system achieve the desired resolution in the azimuth plane, and did atmospheric phenomena degrade system performance. He sought to use proven technology and techniques wherever possible to maintain this focus, minimizing P-40's pursuit of technological advances.

~~(S//TK//REL)~~ In accordance with the experiment's proof of concept objective, Goodyear simplified the radar design and did not include the capabilities needed for an operational intelligence system. For example, the KP-II retained no ability to select the terrain swath being imaged. Resulting hardware underwent extensive modification to ensure reliability in the harsh environment of space. This offered sufficient engineering challenges without involving the additional components needed for an operational system.[15] See figure 4 for more information about P-40's imaging operations.



~~(S//TK//REL~~)
Figure 4—P-40 Imaging Operations
(image: ~~S//TK//REL~~)

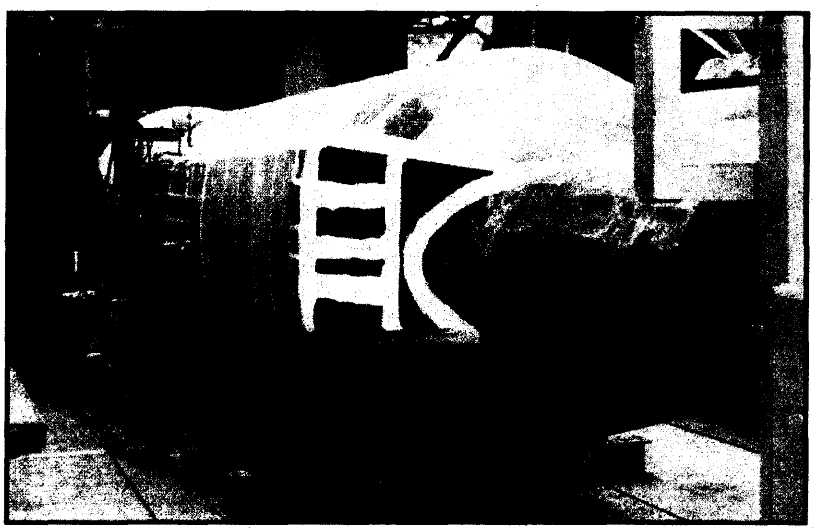
~~(S//TK//REL)~~ The P-40 effort was concerned only with resolution in the azimuth ("map") plane, at right angles to the satellite's ground

15 ~~(S//TK//REL)~~ Information about the payload is drawn from Goodyear Aerospace Corporation, *Engineering Analysis Report No. 1, KP-II Radar System* (Litchfield Park, Arizona: Goodyear Aerospace Corporation, 25 July 1964). SECRET-SPECIAL HANDLING.

track. Bradburn remained unconcerned about range resolution along the satellite's direction of travel because shortening the radar pulses or other simple modifications could readily change it. His goal remained constant: processing space-based SAR data to achieve useful azimuth resolution, thus proving the concept of reconnaissance via space-based radar imagery.

~~(S//TK//REL)~~ Quill's experimental mission would last only 96 hours. During that time the KP-II radar would operate no more than five minutes per orbit, and for no more than three orbits in succession. Three silver-zinc batteries powered the unit, providing a maximum of 80 minutes of SAR collection. These parameters would allow the vehicle to achieve its mission goals.

~~(S//TK//REL)~~ The Corona program's proven flight package of a thrust-augmented Thor booster and an Agena D upper stage would carry the KP-II radar into space. Lockheed engineers expected the Agena to provide sufficient stability for its integrated KP-II payload to function effectively. This allowed them to opt for the simple solution of flush-mounting the radar antenna onto the Agena's outer surface. The 15 foot antenna occupied nearly the entire right side of the Agena (see figure 5), protruding about 2.5 inches from its surface once covered by a protective fairing.[16]



~~(S//TK//REL)~~ Figure 5—Quill Agena vehicle with KP-II antenna (image: ~~S//TK//REL~~) source—Lockheed *System Report 2*, p 1-44.

~~(S//TK//REL)~~ The antenna fairing reduced the strain on the Agena's small engine by detaching after the Thor booster engine cut off. Three of the antenna's four mountings slid along fixed tracks as the vehicle reacted to thermal loads, thereby preventing antenna deformation.[17]

[16] (U) Bradburn, interview.

[17] ~~(S//TK//REL)~~ Lockheed, *System Report 2,* p. 1-139. S-SPECIAL HANDLING.

Once in orbit the Agena would follow a typical early Corona mission profile, flying tail first to facilitate film recovery and terrestrial coverage.

~~(S//TK//REL)~~ Quill reflected the same technological challenges that had led WS-117L engineers to the film-readout and film-return solutions for photographic imagery. Return signals from each pulse of the KP-II radar produced a line on a cathode ray tube on board the Quill satellite. Photographic film moved across the display to record successive radar returns, preserving the data for later analysis.

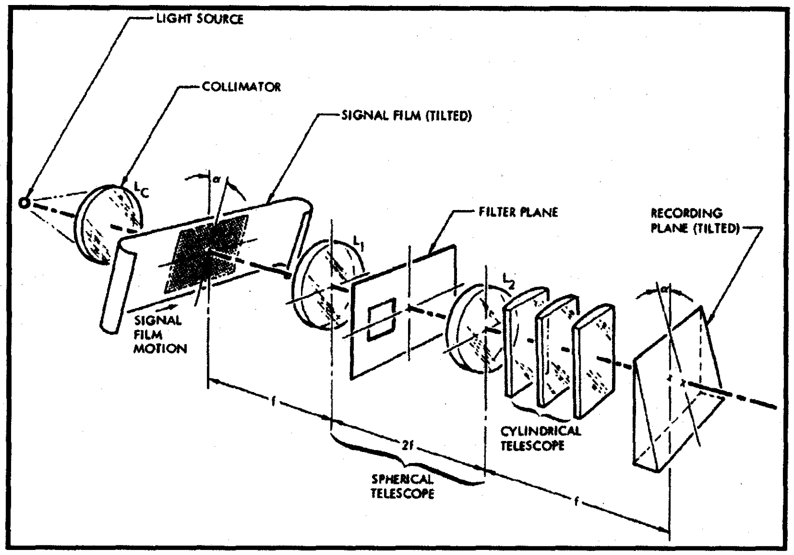
~~(S//TK//REL)~~ The satellite would send that data to the ground in two ways. While the Corona system's film return technology provided a proven method, the desire for a near-real time satellite imagery capability remained alive and well in the Air Force. Strategic Air Command supported Quill, particularly in conjunction with a near-real time capability, as a potential tool for post-strike bomb damage assessments.[18] The experiment accordingly employed an ultra high frequency (UHF) wideband data link to test this potential.

~~(S//TK//REL)~~ The experimental SAR problem was not as challenging as using analog systems to transmit an operational optical image, as contemplated in WS-117L's E-1 and E-2 efforts. Quill transmitted data directly from the KP-II receiver to specialized recorders at the Vandenberg Air Force Base, California, and New Boston, New Hampshire, tracking stations used for the Corona program, and gathered data only when in view of one of those stations. The recorders duplicated the satellite's machinery, translating the raw KP-II data into a cathode ray tube image and recording it on film. Preflight engineering analysis considered this task simple and straightforward.[19]

~~(S//TK//REL)~~ Whether in space or on the ground, this approach preserved the Doppler-coded return signal from the KP-II radar unit as a film transparency. Technicians could convert the seemingly meaningless result into visual imagery using a purpose-built device known as a Precision Optical Processor (see figure 6). The University of Michigan's Lou Cutrona had developed this technique for processing SAR Doppler data in the 1950's, using optics to perform a task beyond the limited capabilities of that era's electronic computers.

[18] (U) Robert L. Perry, *Quill: Radar in Orbit* (NRO, 1973), 1-2.

[19] ~~(S//TK//REL)~~ Goodyear, *Engineering Analysis*, p. 9-1.



(U) Figure 6—University of Michigan Precision Optical Processor (image: ~~S//TK//REL~~)

~~(S//TK//REL)~~ The unprocessed SAR data, although captured on optical film, presented nothing comprehensible to the human eye. Cutrona's technique recognized that optical lenses, when linked to lasers, could perform fast Fourier transforms beyond the capabilities of the era's digital computers. His Precision Optical Processor concept was a holographic computer designed to translate optical film data from a s[redacted]stem into fully focused, fine-resolution optical imagery[redacted]

~~(S//TK//REL)~~ When complete, Quill filled the Agena's three payload sections: barrel, conical, and nose. The KP-II radar system, weighing 370 pounds, went in the barrel section. The recorder system, including the cathode ray tube recorder and the film-supply cassette, weighed approximately 99 pounds and went in the conical section. The reentry capsule, located in the vehicle's nose cone, protected exposed film containing the raw data until it arrived safely back on Earth.[20]

[20] ~~(S//TK//REL)~~ Goodyear, *Engineering Analysis*, pp. 4-1–4-12.

(U) MANAGEMENT

~~(S//TK//REL)~~ With this architecture, P-40's experimental Quill vehicle took full advantage of the equipment and procedures developed for the Corona film-return program. The program itself benefited from experience with WS-117L contractors. When P-40 was first approved, Bradburn had observed that his experience with the earlier effort led him to believe that preliminary budgets underestimated actual costs, and that proposed schedules would slip as contract negotiations unfolded. Bradburn's planning therefore assumed a program cost of [redacted] double Lockheed's 1962 proposal. When negotiations were complete in January 1963, Bradburn's original forecast proved prescient. The program's actual estimated cost stood at [redacted] just under his assumption and well below the [redacted] approved in November 1962. These costs did not include boosters, launches, or space operations.[21]

~~(S//TK//REL)~~ Quill contracts originally called for first launch in April 1964, but even Bradburn's tight focus and insistence on minimal technology development could not prevent delays. Bureaucracy was not the problem. Bradburn had few reporting requirements and good relations with Program B, the CIA element of the NRO running the Corona program. The difficult technical and engineering issues surrounding the P-40 program simply required time to resolve. Like many program directors to follow him, Bradburn believed it was better to launch late with a successful satellite than on schedule with a failure, and so he emphasized thorough testing and a successful first flight.[22]

~~(S//TK//REL)~~ Steady progress continued through the summer of 1964 as the launch date moved to 5 August, and then fell back to 29 August.[23] Payload tests were completed without any indication of problems. The radar and the antenna proved compatible, promising slant range resolution better than 25 feet for best case targets. Technicians had completed installation and testing of equipment at the tracking stations; they also used the completed optical correlator to verify proper adjustment of the recorders. A performance evaluation plan for the mission had also been completed.

---

[21] (U) Perry, 28-31

[22] (U) SAFSP Director, *Quarterly Report*, 31 May 1964. TS/BYE.

[23] (U) Ibid.

~~(S//TK//REL)~~ The Agena D upper stage had passed acceptance testing and awaited its payload at Vandenburg Air Force Base, California. However, problems continued to surface in system-level tests at altitude, and the launch date slipped to 2 November.[24] This date also passed as engineers redesigned a troublesome radar transmitter. That final component arrived at Vandenberg under careful security measures, and by mid-December Quill stood ready for launch. While eight months later than originally planned, this was only 25 months after initial contract award.

(U) LAUNCH

~~(S//TK//REL)~~ With Bradburn in command as launch control officer, on 21 December 1964 the world's first satellite-borne synthetic aperture radar (SAR) awaited liftoff. Controllers brought all systems to readiness 10 minutes before the launch window opened. Quill could then fly within 30 seconds of Bradburn's command.

~~(S//TK//REL)~~ Regulations permitted only official, and protected, personnel within a defined area of Vandenberg during launches. Range safety officers reported a civilian train approaching the safety exclusion area moments before the launch window opened. The launch could not proceed while the train was inside the exclusion area, a delay that might exceed the launch window. Bradburn thus found himself assailed by demands that he launch before the train crossed into the safety zone. He refused, waiting for the planned time rather than implementing an alternative that his personnel were improvising on the spot. The train stopped before it entered the exclusion area and the launch proceeded as planned at 11:08 a.m. Pacific Standard Time.[25]

~~(S//TK//REL)~~ With Quill safely off the launch pad Bradburn headed to the Satellite Control Facility in Sunnyvale and soon learned that the Agena, international satellite designation 1964 87A, had reached a useful orbit and appeared to be functioning properly. Determining if the radar actually worked required several more hours. The ground station at Vandenberg included a video display that would show the characteristic shapes of radar pulses being received and decoded if the Quill system was operating and transmitting. Goodyear, referred

---

[24] (U) SAFSP Director, *Quarterly Report,* 30 September 1964. TS//BYE.

[25] (U) Bradburn, interview, and SAFSP Director, *Quarterly Report,* 30 December 1964, TS//BYE. Bradburn's unclassified account may be found in "The Evolution of Military Space Systems," R. Cargill Hall and Jacob Neufeld, eds. *The U.S. Air Force in Space* (Andrews Air Force Base, MD: Air Force Historical Foundation, 1995), 61-65, U.

to as the "Program Associate Contractor" (PAC) for security purposes, operated this equipment. Later that day Bradburn received the message "PAC Room reports Code One"—radar returns from Quill were showing up on the Vandenberg monitor.

~~(S//TK//REL)~~ Quill's non-rechargeable batteries ran out of power on schedule during orbits 72-73, 26 December 1964.[26] The radar operated fourteen times, imaging large swaths of the northeastern and western United States.[27] Data collected from those fourteen radar passes went to the ground station in view, either Vandenburg or New Boston, over a wideband (UHF) data link in real time. In addition, the onboard film recording system captured data from the first seven radar passes. Technicians developed the film after its 23 December recovery and ran it through the specially made Precision Optical Processor to produce useful images. The only delay in the process came when the courier's flight was cancelled, but the key question had already been answered. The film had achieved azimuth resolution of 7.5 feet—the theoretical maximum from the 15-foot antenna. Reconnaissance by SAR imagery was practical.

~~(S//TK//REL)~~ Quill re-entered the atmosphere during its 333rd orbit. Bradburn and his Program A superiors declared the mission a success well before its 11 January 1965 conclusion. In his 30 December 1964 Quarterly Report, the Program A director said that "vehicle and payload performance were within acceptable limits on all parameters. . . . The radar maps . . . cover about 80,000 square miles. The resolution is better than 15 feet in azimuth and approximately 80 feet in ground range. . . . The volume of data is greater than had been anticipated. Technical evaluation has begun and will be completed in 90 to 120 days." The second payload and its booster stood complete at Lockheed, their launch postponed until the first Quill mission could be analyzed in detail. A third system, without an assigned booster, also neared completion. The program director promised recommendations for the disposition of the remaining Quill hardware in 30 to 45 days.[28]

---

26 ~~(S//TK//REL)~~ Ibid, see also Goodyear Aerospace Corporation, *KP-II Final Report: Experimental Laboratory Investigations BKP-II-16* (Litchfield Park, Arizona: Goodyear Aerospace Corporation, 31 March 1966), pp. 5-6. SECRET-SPECIAL HANDLING.

27 ~~(S//TK//REL)~~ The original mission plan called for 16 radar passes. Available documents do not account for the reduction. Goodyear, *Engineering Analysis*, 1-4.

28 (U) SAFSP Director, *Quarterly Report,* 30 December 1964.

(U) RESULTS

~~(S//TK//REL)~~ The P-40 team had sought answers to several questions. Determining whether satellite-based SAR would work at all remained the primary concern. Figuring out how to make it work best drove other experiments.[29]

~~(S//TK//REL)~~ Quill's evaluation compared the satellite's data film with observation of its ground targets. Original output transparencies from the Precision Optical Processor were magnified 2.6 times and reproduced as paper prints or positive transparencies. The evaluation found neither of those two derivative products suitable for detailed intelligence analysis despite Quill's native resolution:

> ~~(S//TK//REL)~~ The paper prints . . . have a resolution capability of perhaps 6 lines per mm; at the scale factors corresponding to the 2.6:1 enlargements, this poor resolution completely dominates the quality of the imagery. The resulting ground-range resolution is of the order of 90 to 100 feet. The degradations in the positive transparencies . . . are not as severe. In either case, imagery to the scale of the 2.6:1 enlargements is useful primarily for orientation and descriptive purposes only, and not for detailed study of the target complexes. Detailed examinations require the use of enlargements of greater magnification, the use of the original output transparencies, or in special instances the observation of the optical output of the processor prior to recording.[30]

~~(S//TK//REL)~~ The proof of concept experiment succeeded despite this shortcoming. The KP-II radar met P-40's goal of 10-foot azimuth resolution.[31] It illuminated more than 100,000 square miles of U.S. territory, producing useful images of nearly 80 percent of that area. As expected, the satellite's smooth trajectory allowed it to provide clear SAR imagery without the complex motion compensation systems needed on aircraft.[32] Quill's slant-range resolution, not a mission goal and limited by bandwidth, was 45 feet. At the Agena's depression angle this provided approximately 75 feet of ground-range resolution.

[29] ~~(S//TK//REL)~~ Lockheed, *System Report 1*, pp. 37-38.

[30] (U) Lockheed, *System Report 2*, pp. 4-14–4-15.

[31] (U) Lockheed, *System Report 1*, pp. 34-35.

[32] (U) Lockheed, *System Report 1*, p. 146.

~~(S//TK//REL)~~ The resulting imagery held promise for strategic reconnaissance, revealing natural terrain features and human construction. Weather conditions did not seem to have affected the quality of the system's images except for a small area experiencing intense rainstorms. Even then, the imagery successfully revealed the target's underlying structure. When the National Aeronautics and Space Administration launched Seasat in 1978, that "first spaceborne synthetic aperture radar" failed to surpass Quill's azimuth resolution and showed little qualitative difference in its imagery.[33]

~~(S//TK//REL)~~ Quill answered dozens of technical and engineering questions. It showed that analytic models based on aircraft operations worked well for satellites, that imagery processed from transmitted data suffered only slight degradation in comparison with pictures made from recovered film, and that images obtained from orbit could approximate those from aircraft radars using similar technical parameters. It proved that ambiguous target indications could be minimized and that the slight inaccuracy and instability in the satellite platform could be compensated for electronically. It also sampled the average radar reflectivities of several different types of terrain.

~~(S//TK//REL)~~ The orbital experiment met all of its objectives. Lockheed's assessment noted that the system proved its expected ability to produce radar imagery of a consistently high quality by day, by night, and through a variety of weather conditions. It also observed that prevailing conditions in most of the target areas would have prevented successful photographic or infrared imaging. Significantly, the experiment did not reveal anything that would prevent future systems from realizing azimuth and ground-range resolutions on the order of 10 feet.[34] Goodyear engineers continued their research, including suggestions for improving Quill's radar resolution and the quality of its film-based recording system.[35]

~~(S//TK//REL)~~ Evaluation reports all exuded optimism and expectancy. The project's first flight had been highly successful and the path to further experiments, or even an operational system, seemed clear. One report recommended continued use of both Quill's analytical model and experimental aircraft systems in further development of satellite-based SAR. The Lockheed report agreed and recommended

[33] (U) Butterworth; see also [redacted]

(U) Lockheed, *System Report 1,* p. 146.

[35] ~~(S//TK//REL)~~ Goodyear, *KP-II Final Report,* pp. 151-154.

that additional experimental SAR satellites include long-duration power supplies capable of supporting operational missions.[36]

(U) CONCLUSION

~~(S//TK//REL)~~ However, the first Quill satellite's clear success did not necessarily bode well for continuation of the experimental program. Referring to the mission's success, Bradburn asked a fellow officer "What do you do when you come up to bat, and, the first time, you knock a ball out of the ballpark, what do you do then?" The officer replied, "Well, Dave, I think you go down and sit on the bench."[37] On 5 January 1965, Bradburn gave NRO Director Brockway McMillan a preliminary briefing on the mission's results. McMillan agreed with Bradburn's recommendation to remove the second Quill vehicle from the launch schedule pending further results expected the following month.

~~(S//TK//REL)~~ On 11 February, several weeks before contractors completed their evaluations of the mission's product and performance, McMillan received a cable from Major General Robert Greer. The Quill contractors recommended a second launch in fall 1965, but the director of Program A did not agree. In his opinion the first mission had proven the feasibility of satellite-based SAR reconnaissance. Greer felt that further development did not require additional launches, and that an operational use should be defined before space-based experiments resumed. McMillan agreed, and the remaining Quill hardware went into storage until an evaluation committee commissioned by NRO headquarters could complete its report.[38] Program A's financial summary showed a total of [redacted] remaining in Quill's budget.[39]

~~(S//TK//REL)~~ In his quarterly report for June 1965—his last as director of Program A—Greer reported that a further [redacted] had been provided to finish a contractor study, but that otherwise the Quill program had been completed.[40] Apparently none of the work went any further. Three years later, in 1969, the NRO reported that "NPIC [National Photographic Interpretation Center] evaluated the [Quill]

---

[36] ~~(S//TK//REL)~~ Lockheed, *System Report 1*, p. 146-148.

[37] (U) [redacted] interview.

[38] ~~(S//TK//REL)~~ Maj. Gen. Robert Greer to Maj David Bradburn, cable [redacted] 7061, "Disposition of Quill Hardware," 11 Feb 1965. ARC Job 199800073, box 1, folder 106. S//BYE.

[39] (U) SAFSP Director, *Quarterly Report*, 30 June 1965. TS//BYE.

[40] (U) Ibid.

imagery, stated it was capable of providing useful intelligence, and recommended further research and development."[41] In 1972, an NRO Position Paper explained that after Quill's flight:

> ~~(S//TK//REL)~~ It was concluded that no further satellite experiments as such should be conducted; instead efforts should be made to define precisely the system application desired, and then the development of the actual system should proceed. The system application studies, intended to be conducted in parallel with the engineering demonstration, were not decisively concluded. Thus by 1965 the NRO had completed an orbital demonstration, but no agreement had been reached that the proposed application, bomb damage assessment, or any other application, was sufficiently attractive to proceed.[42]

~~(S//TK//REL)~~ Using available technology the NRO had demonstrated the feasibility of an all-weather, day-night, near-real time imaging system that could meet an important Strategic Air Command (SAC) need. Procuring an operational system was a different matter. NRO Director Charyk had been emphatic in authorizing Quill: "The effort is to be strictly experimental in nature and is not to be considered in any sense as an operational prototype or the initial step of an operational system development. . . . The request for proposals should make clear the experimental, rather than the operational prototype or system nature of this effort."[43]

~~(S//TK//REL)~~ Quill's first experimental mission achieved a resolution almost three times better than the early Corona cameras. Some of SAC's intelligence officers favored procuring an operational system, but SAC did not pursue further development.[44] Some of Program A's own officers thought there were good reasons to discount the value of an imaging radar satellite regardless of Quill's success.

---

[41] (U) Memorandum for the Record, "List of Topics for Discussion with ExCom,"13 June 1969. ARC Job 199700046, box 4, folder 8. TS//BYE.

[42] ~~(S//TK//REL)~~ "NRO Position Paper on the NRO Satellite Radar Program," attachment to John L. McLucas to Assistant Secretary of Defense (Intelligence) and Director, Defense Research and Engineering, memorandum, "Synthetic Aperture Radar Surveillance Satellite System," 10 October 1972, ARC Job 199900005, box 2, folder 19. TS//BYE.

[43] (U) Charyk to Greer, 21 November 1962.

[44] (U) [redacted] USAF (ret.), interview with Robert Butterworth, January 2000, Waterton, Colorado. NRO history files, TS//BYE. SAFSP Director, *Quarterly Report,* 30 June 1966.

~~(S//TK//REL)~~ Pointing to Quill's "small area coverage, narrow bandwidth, and low resolution," they argued that SAR could serve neither search nor surveillance purposes. According to this interpretation radar imagery's only useful application lay in providing bomb damage assessment to support SAC's war fighting capability. These critics questioned SAR's ability to execute even that mission in a timely, reliable, and cost-effective manner.[45]

~~(S//TK//REL)~~ Reflecting on the effort later, Flax commented that the real difficulty was opposition from the Intelligence Community.[46] Military leaders offered strong support for proceeding with an operational radar satellite program. SAC was favorably impressed by Quill, and the new Director of Defense Research and Engineering, John S. Foster, Jr., urged Flax and his successor, John McLucas, to build another satellite.[47] Flax agreed that it would be a good idea, but some in the CIA resisted. Quill had proven that satellite-borne SAR imagery was feasible, but the Intelligence Community thought and worked in terms of optical imagery. In those terms a radar satellite would not be useful until it attained much finer resolution.

~~(S//TK//REL)~~ Flax did not believe that he should press the matter in the absence of agreement from the Intelligence Community. He confronted the institutional wreckage left by his predecessor, Brockway McMillan, and worked under a new NRO charter intended to repair that damage and prevent its recurrence. As a result, Flax paid careful attention to bureaucratic diplomacy and based his decisions and recommendations on solid technological grounds.

~~(S//TK//REL)~~The SAR satellite proposal, however, was not a question of how to do something, but whether something was worth doing. A technical major advance was needed before an operational radar satellite could receive broad support. Evolutionary improvements in film emulsions, platform stability, signal timing, and the like would not be enough to make satellite SAR imagery comparable to that obtained by optical cameras.

[45] (U) Draft manuscript, "Satellite Reconnaissance," marked [redacted] Study, Not Released," July 1963, pp. 20-21. ARC Job 199700046, box 4, folder 14. TS//BYE.

[46] (U) Dr. Alexander Flax, interview with Robert Butterworth, 21 November 2002, Potomac, Maryland. NRO history files. S//BYE.

[47] (U) John S. Foster, Jr., interview with Robert Butterworth, 4 December 2002, Washington, D.C., Foster to Flax, memorandum, 22 November 1966, "Special Support Activities RDT&E FY 1968 Budget," ARC JOB 199800073, box 1, folder 118. TS//BYE.

~~(S//TK//REL)~~ No physical artifacts, and few documents, from the Quill experiment survived. The Thor/Agena launch vehicles were recycled into the Corona program, and the remaining radar equipment was broken up and destroyed. "It was heartbreaking," [redacted] said:

> ~~(S//TK//REL)~~ "Someone came [to Litchfield Park] and had the right kind of credentials, and wanted to know if any hardware existed from the KP-II program. I said no, all had been destroyed. What did you want to do with it? He said they wanted to put it into the Smithsonian museum. Sorry, all gone. Unfortunate that the program has remained so highly classified. But that's the way it is. I'd like to be able to tell my son what I had accomplished and what I was a part of, but I can't and I won't."[48]

~~(S//TK//REL)~~ Quill represents a technological triumph, the demonstration of a space-based reconnaissance capability bordering on science fiction just three years after the NRO's birth. The off-the-shelf technologies that it harnessed, however, held limited intelligence value in the short term. Considerable advances were required before the wider intelligence community would see any need to translate the proof of concept into an operational system. The search for advances ultimately drove development [redacted]

~~(S//TK//REL)~~ As a harbinger of things to come, Quill's existence had to remain classified until space-based imaging radar, the U.S. Intelligence Community's use of it, and the existence of the organization that brought its parent P-40 program to fruition were all known to the public. Those events have all come to pass, leading to the 2009 declassified acknowledgement of Quill as a 1964 NRO experiment in radar imaging. In due course, the full story of the NRO's remarkable achievements with Quill will be released to the public.

48 (U) [redacted] interview.

CENTER FOR THE STUDY OF
NATIONAL RECONNAISSANCE

AUGUST 2011